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# GEOGRAPHICAL INFORMATIONAL SYSTEMS FOR SUSTAINABLE ARCTIC TECHNOLOGY

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## ABSTRACT

The essential part of innovations and installations is created and lives in natural conditions. Understanding and knowledge about the environment is the main issue for sustainable development in harsh regions such as the Arctic. The modern technique to represent environmental data is Geographical Information System (GIS), which has become very important for industry and management, particularly within contemporary technology projects.

The special GIS is developed at the University Centre in Svalbard (78$^o$ North) in the frame of Sustainable Arctic Marine and Coastal Technology (SAMCoT) project associating several industrial and educational partners. It shows important for arctic technology issues pertaining to fixed and floating structures, topography of coastal zone and erosion, sea currents, sea ice properties, installed equipment and obtained data. The exposition of physical-geographical conditions, natural resources deposits and current exploration activities creates the background for future inventions.

There are 5 hierarchical levels of mapping and presenting materials: from an overview of the whole European Arctic to detailed plots of key sites with high resolution 3D models based on Laser Scanner point clouds. The main locations for project activities presented as key sites are in central Svalbard in Van Mijenfjord (closed by island gulf with long lasting sea ice, coal mine and port activities), Advent Fjord (main settlements and port activities), and Tempelfjord (glacier outlets); and in North-West Russia at Baydara Bay, and Varandey. There are also places of research vessels survey in Barents Sea and Fram Strait.

Data comes from published materials (available to the public) and field work measurements performed by project participants (available internally). The GIS gives the possibility to run mathematical models on real maps, taking natural conditions and processes into consideration. On-line version will make the results accessible for the colleagues from different places.

## INTRODUCTION

### *General definitions and purpose of GIS*

Geographic Information Systems (GIS) is a system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. Broadly speaking, GIS also includes the operating personnel and the data (Tomlinson, 2011). Spatial features are stored in a coordinate system (latitude/longitude, state plane, UTM, etc.), which references a particular place on the earth. This fact differentiates GIS from Computer-aided design (CAD) and other graphical computer applications. Spatial data can be "re-projected" from

one coordinate system into another, so that data from various sources can be brought together into a common database and integrated using GIS software.
Spatial features are associated with attribute tables, describing the features. Real objects (such as roads, elevation, depth, industrial construction, etc.) can be presented in GIS as two abstractions: discrete objects (e.g., a house) and continuous fields (such as rainfall amount, or bathymetry). Traditionally, there are two broad methods used to store data in GIS for both kinds of abstraction mapping references: raster images (digital terrain model or aerial/space image) and vector (points, lines and polygons). Files of different types can be combined and shown on the screen as "layers". A combination of layers gives us the map, reflected available information.
By merging cartography, statistical analysis, and databases, GIS allows us to view, understand, investigate, interpret, and visualize data in many ways thereby revealing relationships, patterns, and trends in the form of maps, globes, reports, and charts.

In 2012, the 50$^{th}$ anniversary of GIS has been celebrated. The first event was the establishment of the Canada Land Inventory (CLI) in 1962. Roger Tomlinson, known as the father of GIS, convinced the head of CLI that computers could be used to automate map analysis. In 1968 Roger Tomlinson published the first scientific article on GIS "A Geographic Information System for Regional Planning". In 1969, Jack Dangermond, who studied at the Harvard Lab for Computer Graphics, co-founded Environmental Systems Research Institute (ESRI) with his wife Laura. ESRI would become in a few years the dominate force in the GIS marketplace and create ArcInfo and ArcView software. The first conference dealing with GIS took place in 1970.
Hardware and software have been developed significantly since that time. Electronic maps have become common for most computer and advanced telephone users. One can find more then 100 ml hits on Google for GIS. Now GIS is a necessary component of territorial planning and management on all scale levels from local communities to country governments and international organisations. Most engineers already use GIS. A large number of universities gives courses on GIS and its usefulness is well known. Google maps service, which applies GIS, is used by millions all over the world.

***GIS in industrial companies***
Almost all large industrial companies, operating within the environment with oil and gas, transport and mineral development, and ecological and research organizations have their own GIS software and GIS experts employed. Shell has been using ArcGIS for more than 20 years. Shell specialists have demonstrated their experience in operative map production during Kulluk Tow Incident in December 2012, when a special web-site showing the development of events, map and 3D models was created (http://www.kullukresponse.com).
Another example of an active GIS user is Statoil. Statoil has 20,000 employees worldwide with operations in 34 countries and there are currently over 1,000 registered users of GIS. Included in these numbers are GIS analysts, "super-users", a dedicated data management group and IT operation resources. Many more are general consumers of internal web mapping information through the intranet. Statoil uses GIS technology to analyze, disseminate and visualize exploration and production information. Statoil's paper map products, such as field layouts (with pipelines, cables, platforms and other infrastructure objects), overview of installations, discoveries, and current licensing status for petroleum activities on the Norwegian continental shelf are well known. The map includes a table showing company operators and partners which has been published in the 25$^{th}$ volume of ESRI Map book (http://www.esri.com). Statoil web maps and map services are offshore infrastructure maps with near real-time vessel tracking, inspection web maps (pipelines and structures), web map

with links to digital videos through web interface, prospective activity atlas and more. The first conference for Russian oil-gas companies, using ArcGIS has been held in May 2002. Ten years of development has been analysed in 2012 (ArcReview, 2012, see also Enterprise GIS of Samotlorneftegaz - http://www.dataplus.ru/news/)

***GIS-based web-resources and web-based GIS tool for Arctic***

There are several very interesting and useful sites, showing Arctic environment and sea ice behavior. They are quickly developing and could be used for estimation of natural conditions and modeling in Arctic Technology. Here are some main examples.

The *Environmental Response Management Application* (ERMA) is a web-based GIS tool that assists both emergency responders and environmental resource managers in dealing with incidents that may adversely impact the environment. ERMA integrates and synthesizes various real-time and static datasets into a single interactive map, thus provides fast visualization of the situation and improves communication and coordination. This site was designed by NOAA's Office of Response and Restoration the University of New Hampshire and the U.S. Environmental Protection Agency. Arctic ERMA is a pilot project supporting the efforts of the Arctic Council's Emergency Prevention, Preparedness, and Response Working Group (https://www.erma.unh.edu/arctic/erma.html).

*Sea Ice Index*, by National Snow and Ice Data center in Colorado (Fetterer et al, 2002, updated 2009) provides a quick look at Arctic- and Antarctic-wide changes in sea ice. It is a source for consistent, up-to-date sea ice extent and concentration images and data values from November 1978 to the present. The main parameter is Sea Ice Concentration which is used to make spatial images of ice extent and concentration, data files of hemisphere-wide ice extent and ice-covered area over time, and times-series graphs of sea ice extent.

*The Cryosphere Today* is a web site devoted to the current state of the cryosphere. Sea ice data sets since 1979, spectacular animation of ice cover shrinking in the Arctic in recent years, (1978-2006 and 2001-2006) can be found here http://arctic.atmos.uiuc.edu/cryosphere/.

*Norwegian Meteorological Institute* provides ice charts, oceanographic information and data for the Nordic Seas and Arctic Ocean from Greenland to the west including Kara Sea http://met.no/English/Ocean_and_Ice.

*GIS server ESIMO* (in Russian) (http://www.aari.nw.ru/projects/ECIMO) provides over 150 layers with observations, diagnostic and prognostic hydrometeorological and ice information). The ice charts of the Arctic Ocean are posted here. During the summer period (1.VI-30.IX) charts depict distribution of generalized categories of sea ice total concentration for the intervals 1-6/10s and 7-10/10s. During the winter period (1.XI-31.V) - distribution of generalized sea ice stages of development (ice thickness) - nilas, young, first-year and old ice are depicted. Ice charts are issued every Thursday. They are based on automatic generalizations of regional ice charts which are compiled on a basis of analysis of satellite (visible, infra-red and radar) information and reports from coastal stations and ships.

***GIS in the project, devoted to Arctic Technology***

Since 2011 the University Centre in Svalbard has been involved in SAMCoT project (Sustainable Arctic Marine and Coastal Technology), associating several industrial and educational partners. The main responsibilities of UNIS in the project – data collection and process modeling – made it necessary to organize and store obtained data; to create possibility of mathematical modelling on the base of these data. For these purpose SAMCoT GIS has been constructed, using the modern GIS software. The main intention of the paper is to describe this GIS as example of GIS tools application of geoinformatics tools for the project aimed to develop modern technology in harsh Arctic conditions.

## RESULTS

### *SAMCoT GIS. Concept and structure*

SAMCoT GIS is the storage of geographically located data and the tools for data exchange and analysis. The project aims to develop technology in the Arctic, and takes into consideration a large territory from Greenland to Novaya Zemlya. Data for modelling are collected in many different places. A lot of parameters in the models, such as characteristics of sea currents, and permafrost have geographical sense. So it is quite natural that there is a demand to present the data and the places of the work on the map. The objects and descriptive data could vary largely in size from several meters long ridges to hundreds kilometres of buoy drift trajectory. To show all activities and key sites we need the map to embrace thousands of kilometres. The large and small scale maps have different degrees of generalisation. On the map for the whole Atlantic sector of the Arctic (small scale), we will see the cities as points and small circles; while the buildings and pier elements will be presented on the harbour scheme or aerial photograph (large scale). That's why the maps should be presented in different scales and hierarchical structure of GIS is necessary (Table 1).

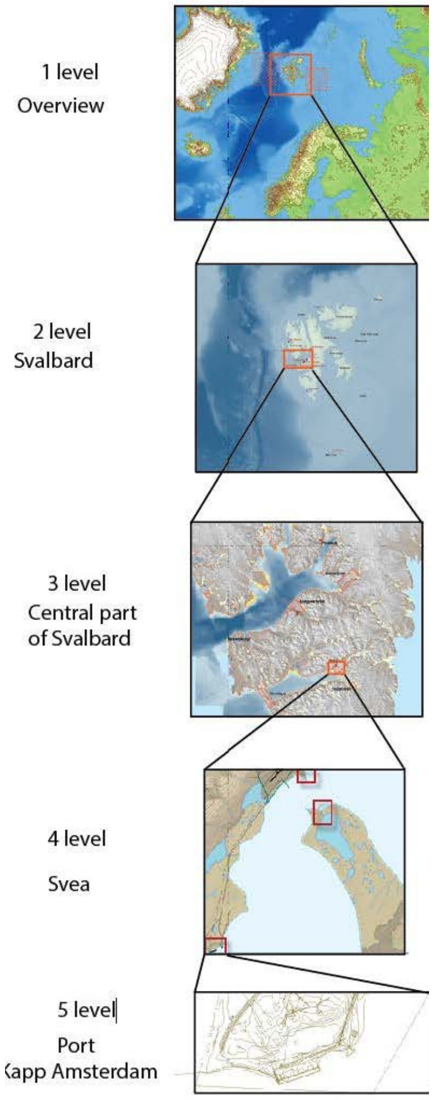
Five hierarchical levels have been designed for the GIS created for the project. This GIS will be described in the article as an example. The basic map scale changes from 1:20 000 000 to 1:1000 through these five levels, consequentially zooming and approximating the point of consideration from overview of the whole Atlantic Arctic to the individual industrial objects. In Table 1, the zooming to coal port Kapp Amsterdam in the mining settlement Svea, on Svalbard is presented.

As it has been mentioned the electronic maps consist of several layers and the appearance on the screen and in printed version depends on the combination of the layers. For all levels and key sites the following structures have been created: 1) basic map, showing the natural geographical environments (relief, bathymetry, coastline, space or aerial images), 2) infrastructure and population (countries and settlements, industrial objects, deposits and pipelines), 3) special technology part, showing places of field work, installations for measurements, data and the results of work. The first and second parts are rather stable, while the third is quite dynamic part, because the data is updated throughout project progress and implementation.

There are two regions under consideration on the 2nd level - Svalbard with surround water area and Russian Northern European Coast Zone. They are zooming on the 3rd level to central Svalbard and Yamal Peninsula area. There are now four regions in consideration on the fourth level. These are 3 key sites in the central Svalbard (Svea area, Longyearbyen area, Temple Fjord) and Baydara Bay in Russia. There are 13 industrial objects and key sites with installation for measurement in consideration on the fifth level. For example, the coal port and plastic jetty in Longyearbyen and Kapp Amsterdam port in Svea are key sites for monitoring of ice deformation; Akseløya, Von Post and Valunden Lake - for investigation of currents and tides, Vestpynten and sites near Svea are assessed for coastal erosion.

Future maps and data are planned through SAMCoT GIS to accumulate and demonstrate for each of key sites: 1) Digital model of terrain and bathymetry, 2) Coast line and topography (isolines), 3)Tidal fluctuation features, 4) Geology features including wells and mechanical properties, 5) Permafrost characteristics, 6) Measurement installations and the results, 7) Constructions, their characteristics including the date of establishment, 8) Scanner images, 9) Ice condition characteristics, 10) Hydrology and sediments transport, 11) Meteorological stations and their data, 12) Photos with description, linked to the locations, 13) Articles, related to the area and investigations that have been conducted, 14) Web-links.

Table1 SAMCoT GIS hierarchical structure

| Scale level and Goals | Example of map and view in ArcMap | Layers and Objects | Reference scale |
|---|---|---|---|
| 1. Overview of working areas and environmental and industrial situation |  | Basic map<br>Key sites<br>Industrial objects<br>Coastal erosion | 1:15 000 000<br>1:20 000 000 |
| 2. Overview of key areas, ice drift, environmental features. | | Basic map<br>Key sites<br>Buoys trajectories<br>RV routes | 1:2 500 000<br>1:5 000 000 |
| 3. Show the place of work and environmental features. | | Basic map<br>Key sites<br>Coastal erosion | 1:100 000<br>1:500 000 |
| 4. Work places and results | | Industrial objects,<br>Measurement sites and results,<br>Aerial images,<br>Photos | 1:25 000<br>1:75 000 |
| 5. Industrial constructions and behaviour in hard condition. | | Ice deformation,<br>Tide, Currents, Wells,<br>Locations of installation (f.i. thermistor strings) | 1:1 000<br>1:2 000 |

***Program tools and software***

SAMCoT GIS is created on the base of ArcGIS 10 software, developed by Environmental Systems Research Institute (Esri - http://www.esri.com/ ). The headquarters of Esri is in Redlands, California. It has 10 regional offices in the U.S. and a network of 80 international distributors with about a million users in 200 countries. While there are alternative products available from other traditional vendors such as MapInfo and Intergraph, Esri has a dominant share of the GIS software market, the ARC Advisory Group estimate that ESRI's market share exceeds 40%. So ArcGIS is the most common software to create GIS. UNIS has license for ArcGIS since 2006.

There are also free applications for viewing GIS data, such ArcGIS Explorer, ArcReader, That means that GIS created at UNIS on the professional ArcGIS Desktop base by GIS expert, could be used by not GIS experienced people, who would use free ArcGIS viewing

tools and simple explanation. There are also possibilities to make on-line version, server and mobile options. ArcGIS Online allows sharing and search of geographic information, as well as content published by Esri, ArcGIS users, and other authoritative data providers.
Currently we use ArcGIS 10.1 version, launched by Esri in June 2012. This version makes it simpler to use mapping and geospatial analytics for inexperienced users. Any GIS resource, such as maps, imagery, geo databases, and tools, can be delivered as a web service.
ArcGIS for Desktop consists of several integrated applications, including ArcMap, ArcCatalog, ArcToolbox, ArcScene and ArcGlobe. ArcMap is used to view, edit and query geospatial data, and create maps. The ArcMap interface has two main sections: a table of contents on the left and the data frame(s) which display the map (Figure 1). Items in the table of contents correspond with layers on the map. ArcCatalog is the data management application, used to browse datasets and files, to show what data is available, and to preview the data on a map. ArcCatalog also provides the ability to view and manage metadata for spatial datasets. ArcToolbox contains geoprocessing, data conversion, and analysis tools.

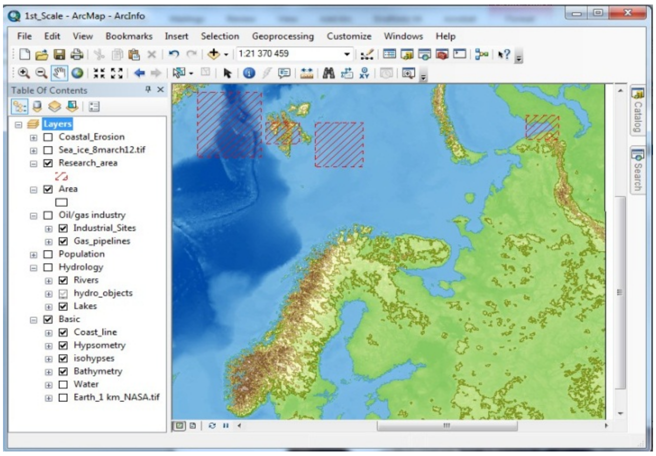


Figure 1 ArcMap program and view for 2 dimensional images. 1st scale level.


Figure 2. 3D view in ArcScene of Longyearbyen with key sites pointed

ArcScene and ArcGlobe are specialized viewing applications within ArcGIS 3D Analyst, yet they operate differently. ArcScene is optimized for viewing and analysis of smaller datasets, such as a specific local area (Figure 2). ArcGlobe is designed to be used with very large datasets. It has a sophisticated caching mechanism that indexes and organizes all your data into tiles and level of detail. Once all the data is loaded, this allows for fast display and visualization as you zoom in and out, pan around, and navigate to different places in your ArcGlobe scene. All these program applications are used for SAMCoT GIS. See example on Fig. 1.and 2.

***Data and metadata***

There are basically two types of data in our GIS: 1) ready data - opened, published or licensed, 2) data obtained and processed in the courses of projects. Both types of data should be prepared for GIS, presented in suitable ways and described to show the features of data and to give the necessary credits.

For the 1st and 2nd scale level mainly world spread maps have been used. They are the world map, delivered by Esri together with ArcGIS package and IBCAO -International Bathymetric Chart of the Arctic Ocean available on (http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/). But having the Atlantic Arctic in the centre we had to change geographical projection and cut the territory that taken into consideration. It allowed to reduce file sizes significantly and to concentrate attention on the main objects.

For 3rd and 4th scale local geographical maps have been used. So the maps and layers provided by Norwegian Polar Institute in the frame of “Norge Digital” are used for basic map for Svalbard. “Norge Digital” is the Norwegian nation-wide program for co-operation on establishment, maintenance and distribution of digital geographic data (http://www.statkart.no). UNIS is part of Norge Digital so has a right to use the material for scientific purposes. Some data comes from the SAMCoT partners. For example, the ready layers showing the key site of Baydara Bay have been provided by research teams from Moscow State University and State Oceanographic Institute (Russia) in the frame of the collaboration project. Some data are collected during field work, as for example ADCP and CTD measurements, laser scanner point clouds, and thermistor strings recordings. Such data are prevailing on the 5th scale.

Metadata is very important. Metadata describes GIS data and is defined as “data about data”. It provides information about a certain item's content. For example, an image may include metadata that describes the size, the color depth, the image resolution, when the image was created, and so on. It is especially important for GIS, accumulating the work of many people and organizations, as all necessary credits should be recognized. Projection and reference scales are significant for maps. The sections containing the field data should contain information about time and weather condition during sampling or measurement, devices used and so forth. Keywords and Meta tags could be used by search engines, helping to find needed data.

The special service to create and use metadata exists in ArcGIS software. It is ArcCatalog, showing all sections and layers of GIS, and contents, preview and description for all items as well. The main elements of “Description part” for all items are the name, file type, image, tags, summary, description with explanation of how this layer has been created, credits, and access rules. See the example of description of “Laser Scanning” layer in SAMCoT GIS in Figure 3.

The substantial question for GIS and data base is the quality of data. Special maps showing the quality of data can be done. For example, in different places of Svalbard the diverse types of measurements concerning the coast have been done by “Kystverket” (the Norwegian Coastal Administration, http://www.kystverket.no/en/), that defines the different quality of data. In the most thoroughly studied areas the density of measurement is more than 200 points per square km, in the less explored areas there is only one point in such a grid. Using the ArcMap tools the mosaic of data density for bathymetry has been done for the central part of Svalbard.

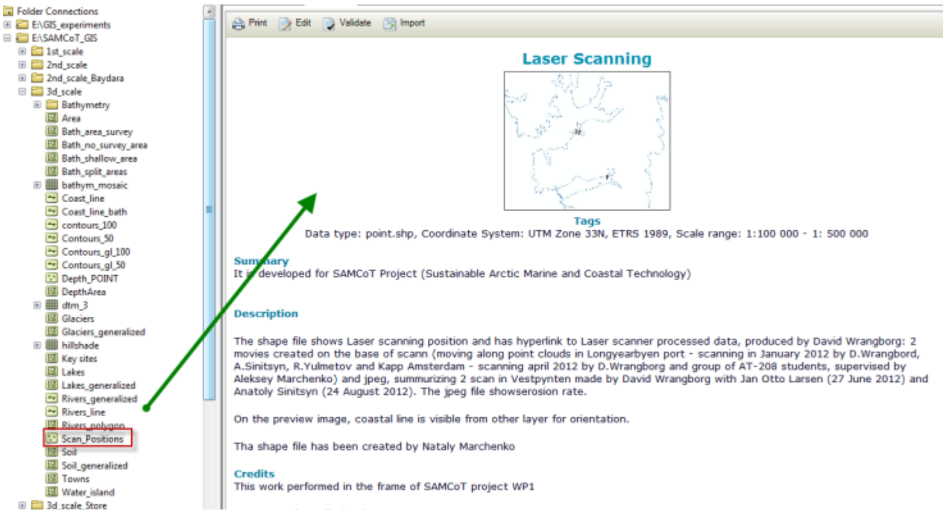


Figure 3 The ArcCatalog view with layer, containing hyperlinks to scanner animation

There are several programs, called "project" inside GIS, which organize data and layout for ArcMap/ArcScene. These are files with extension (.mxd), devoted to each hierarchical level and key site. They can be combined in the data base. By clicking on the icon, one can open the ArcMap or ArcScene program with the combination of layers, presenting a map. For example, by clicking on the project icon of 1$^{st}$ scale, we open the project with maps and layers, showing the whole Atlantic Arctic sector. It has the next group of layers and sublayers: 1) Basic map (Coastal line, Hypsometry, Isohypses Bathymetry, Water, Earth_1 km_NASA.tif), 2) Coastal Erosion, 3) Research Areas, 4) Oil/gas industry (Industrial Sites, Gas_pipeline), 5) Population (Cities, Country bound, Countries). After opening the project, one can combine the layers to obtain the suitable view, get data, statistics, to make analysis and so forth.

## DISCUSSION

The Arctic Technology GIS at UNIS is currently under construction. However, there are already several examples of its application that can be discussed and used further by other research and industrial teams for their projects. The use of GIS in coastal erosion investigation is presented in the article by H.Tangen, N. Marchenko, and M. G Bæverfjord, "Coastal Erosion in Svalbard. Investigation and presentation in GIS" (Tangen et al, 2013). The following are some cases showing how AT GIS has been implemented to create the maps and images for articles, reports and presentations; to prepare data for modelling; and to show the results of measurements and modelling.

### *Performing field data on the map*

The most required and visible application of GIS is presentation of the field work sites with possible links to the results. Very often the route of research vessels (Fig. 4), research teams by scooter or by foot, and trajectories of buoy drifts should be shown on a map. Having them on a map, we can use the information about environment from other sources. For example, by displaying the buoy trajectory on the map we can analyse it together with data about see currents, wind speed and direction to understand the movement in regional and global context. The demonstrations of Laser scanning results in GIS (Fig.5) are quite spectacular and useful.

Figure 4 The track of RV Lance during the survey in April 2012

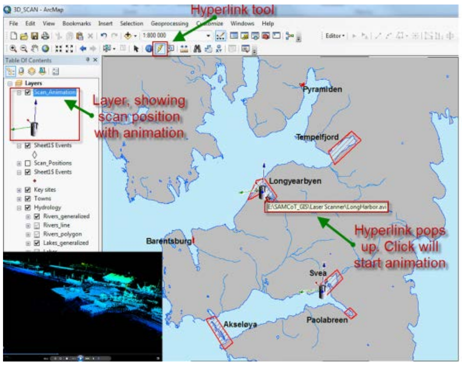



Figure 5 The ArcMap view with layer, containing hyperlinks to scanner animation, running in Windows media player (down left corner)

By putting on the map the data of ADCP and CTD measurements in water masses we can take into consideration the bathymetry, oceanographic and meteorological data.

Usually data from measurements come in the form of navigation files with coordinates from GPS and a file set produced by software designed for the measurement devise. So ADCP measurements of sea current provide us with the set of files NR1-GPS showing the values of speed and direction in each time moment (as defined) for different depths. They can be processed and implemented in ArcGIS.

***3D modeling***

Another application of GIS is 3D analysis of field measurements. Actually almost all real objects: terrain and constructions have volume and 3 coordinates, but the main means of representation are 2 dimensional, on both paper and computer screen. So a lot of efforts in general are used to display the main features of 3D entities, beginning from the topographical maps, showing elevation level by isolines ending with stereoscopic TV. There are a whole set of computer programs to create 3D view. The essential part of them has esthetical and artistic reality as a central purpose (Cantrell, Yates, 2012).

From the technological point of view the possibility of measurement and estimation is most important. Visualization and calculation of current and eventual deformation and stability are the main topics for port and coastal constructions.

The main technique for 3D modeling is *ArcGIS 3D Analyst*, that provides advanced visualization, analysis, and surface generation tools. Using ArcGIS 3D Analyst, one can view large sets of data in three dimensions from multiple viewpoints, query a surface, and create a realistic perspective image that drapes raster and vector data over a surface. *ArcScene* is specialized for viewing applications within ArcGIS 3D Analyst. ArcScene is optimized for viewing and analysis of smaller datasets, such as a specific local area. Once all the data is loaded, this allows for fast display and visualization as you zoom in and out, pan around, and navigate to different places.

On the image, created for Longyearbyen area (Figure 1), high resolution aerial photos are based on the digital model of the relief. This makes an image similar to a photo taken from the plane. But all pixels in this image have 3 real coordinates and the different measurement (distance, volume and so on) can be done here. The main feature, visibly differentiating an ArcScene image from an aerial photo, is the possibility to turn and decline the image in any desirable direction. The example of using the data of ice ridge measurement by electromagnetic antenna EM31 during field work on drifted ice in the Barents Sea (RV Lance survey, April 2012) is shown in Figure 6.

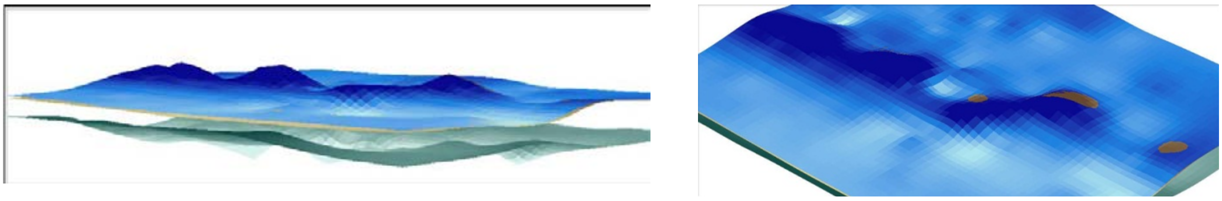



Figure 6 3D model of the ice ridge between Edgeøya and Hopen. Blue – snow surface, Brown – ice, Green – ridge bottom. Data provided by AT-208 UNIS course.

The main tool for obtaining large scale data was Laser Scanner Riegl VZ-1000 and its software. The use of this device is described in the article “Laser Scanning in Arctic Sea Ice Research” (Wrangborg and Marchenko, 2013).

***Providing data for modelling***

A very important and frequently required task for GIS in the technology project is providing data for modelling. For example, to run the models simulating tide water movement one needs the grid with depth value for defined territory and accuracy. ArcGIS tools allow one to take bathymetry data in DTM format (digital terrain model) available on the internet or provided for special order and to cut planned for investigation region from large territory. The next step will be to prepare raster with necessary size of cells, take the depth for each cell of the grid and export data in a suitable modelling format: Excel, ASCII and txt file. Of course, it is possible only to generalize data or make the cells bigger, but quite often for modelling the rough net is enough. Sometimes transformation from one projection to another is necessary.

## CONCLUSIONS

Using a map is very natural for projects dealing with environment. GIS, as a modern mapping technique, helps to solve problems by presenting the data in understandable and easily shared way. Many disciplines, including Arctic Technology can benefit from GIS, and can make the modelling more realistic and applications more useful.

It is expected, that future work will show and reveal the new advantages of GIS. One such possible application is to investigate the sea currents in the Svalbard fjords that significantly influence sea ice action on port construction in winter. Several measuring campaigns with the ADCP, CTD have been done to find out the regularities of sea current speed and direction. GIS map shows the dependence of the currents of tidal phase and particularities of fjords and will give possibility to simulate the variation of ice load on the coast and industrial structure. Another direction of the work is assessment of industrial impact on the environment using aerial images together with geochemical profiling. It is very important to estimate the grade and rate of landscape transformation under anthropogenic influence in the fragile Arctic nature. Mapping in GIS with will bring out the scale of degradation and possible risks for future development.

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